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Previc, Fred
Mullen, Tom

USAF School of Aerospace Medicine
Human Systems Division (AFSC)
Brooks AFB TX 78235-5000

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Air Force Office of Scientific Research
Bolling AFB DC 20332

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This study compared the latencies of visually induced postural changes and self-motion perception under identical visual conditions. The result indicated that a wide-field visual display moving in roll elicits postural tilt in the direction of scene motion long before the subject begins to perceive illusory self-motion (vection) in the opposite direction. The significant delay in perceiving vection is hypothesized to at least partially result from the inhibitory influence of vestibular inputs upon visually induced self-motion perception.

Visual; Vestibular; Posture; Vection; Orientation

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Short Communication

A COMPARISON OF THE LATENCIES OF VISUALLY INDUCED POSTURAL CHANGE AND SELF-MOTION PERCEPTION

Fred H. Previc* and Thomas J. Mullen†

*Crew Technology Division, United States Air Force School of Aerospace Medicine, Brooks AFB, Texas
†Man-Vehicle Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
Reprint address: Dr. Fred H. Previc, Crew Technology Division, Armstrong Laboratory, Brooks AFB TX 78235-5301

Abstract – This study compared the latencies of visually induced postural change and self-motion perception under identical visual conditions. The results showed that a visual roll stimulus elicits postural tilt in the direction of scene motion and an increase in postural instability several seconds before the subject begins to perceive illusory self-motion (vection) in the opposite direction. Postural and vection latencies correlate highly with one another, but bear little relationship with the magnitude of either sway or vection.

Keywords – visual-vestibular interaction; posture; vection; spatial orientation.

Introduction

Investigations concerning the effects of visual scenes on spatial orientation have traditionally employed postural sway and illusory self-motion perception (vection) as primary measures (1). While many aspects of visual orientation are qualitatively similar for the two measures (2), it has been shown that the onset latencies of postural change and vection are not identical (3), contrary to the original suggestion of Dichgans and Brandt (1). Roll vection generally has a minimum delay of several seconds under most conditions (1,4,5,6), whereas one recent report indicates that the lag in postural change may be less than one second (7).

In order to determine more precisely the relationship between the two latency measures, this study systematically compared the onsets of visually induced postural change and self-motion perception under identical visual conditions. A secondary purpose was to assess how well the two latency measures correlate with their respective magnitude measures (that is, sway amplitude and vection magnitude), in view of recent evidence that vection latency and magnitude may be largely independent of one another (5).

Method

This experiment was part of a larger study in which the effects of roll, pitch, and linear visual scene motion were assessed. However, since the latter two conditions elicited much less reliable reports of vection, the comparison between postural change and vection latencies was restricted to the visual roll condition.

A total of 12 subjects participated in this experiment. All subjects were either full-time or summer personnel at the USAF School of Aerospace Medicine (USAFSAM), and ranged in age from 18 to 45 years. Each subject possessed a visual acuity in each eye equal to 20/25 or better, with or without correction, and no subject showed any evidence of vestibular abnormality on the stepping and sharpened Romberg tests.

The experiment was conducted in the USAFSAM Visual Orientation Laboratory

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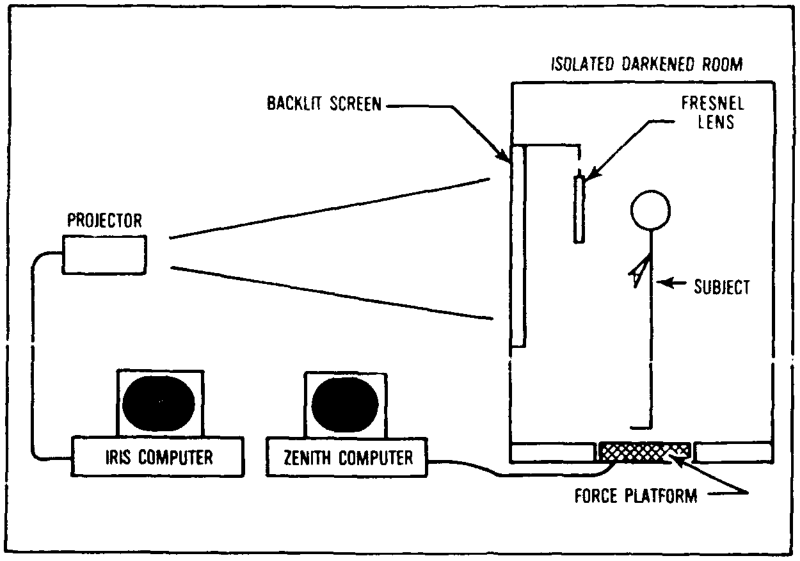

Figure 1. A schematic diagram of the USAFSAM Visual Orientation Laboratory. Images are generated on a Silicon Graphics IRIS 3130 computer and transmitted to a Sony 1030Q projector. The enlarged image is then rear-projected onto a vertically adjustable viewing ensemble containing a Fresnel lens. Subjects view the images inside a darkened booth while standing on a force-measuring platform. The postural output is then amplified and sent to a Z-248 computer for subsequent analysis.

(Figure 1). The laboratory includes (a) a Silicon Graphics 3130 IRIS computer workstation, (b) a Sony 1030Q CRT video projector, (c) a subject booth containing a Draper Cine-15 viewing screen and Fresnel lens assemblage on which the enlarged image is projected at optical infinity, and (d) an Advanced Mechanical Technology, Inc. (AMTI) force-measuring system that includes a 46.4 × 50.8 cm OR6-5 force platform, an SGA 6-channel strain gage amplifier, and a Zenith 248 computer. Both the video projector and the viewing ensemble are adjustable in height, so that the center of the projected image is at eye-level for each subject while standing on the force platform.

The stimuli consisted of approximately 100 small white squares randomly positioned against a dark background. The squares moved either clockwise or counterclockwise in the frontal plane at a velocity of 25°/s, which is at or near the optimal value for eliciting roll vection in most subjects (1,4). The squares ranged from 0.5° to 2° in diameter, and their peak luminance was 6 cd/m^2 at the center of the display. The overall field of view encompassed by the Fresnel lens was 81° vertically by 95° horizontally.

Subjects were exposed to two trials each of the clockwise and counterclockwise scene motion. Each trial consisted of a 10-s baseline interval during which the squares were stationary, followed by a 50-s period of roll motion. The subject's center of pressure and postural moment (a highly related measure of postural sway) were sampled at 20 Hz using the AMTI BEDAS-2 software package.[1] In turn, two measures of lateral sway were extracted from the center-of-pressure data: (a) lateral sway *bias* (that is, the mean y-axis deviation during the stimulus interval relative to the mean baseline position); and (b) lateral

[1]The postural moment is the product of the subject's force (that is, his or her weight at 1 *g*) and distance from the center of the platform. Hence, the deviation of the center of pressure and the postural moment basically record the same information. Since, however, the AMTI software package uses the *moment* measure in its channel (temporal) analysis and the center-of-pressure measure in its stabilogram, we retained the original units in our own analyses.

sway *amplitude* (that is, the mean y-axis deviation from the average position during the stimulus interval).

In addition to the postural measurements, the latency and magnitude of subjects' vection reports were also quantified. The subject responded "now" whenever he or she first experienced the sensation of rolling opposite to the scene motion, and rated the magnitude of the vection on a 5-point scale at the end of the trial. The 5 vection ratings were "little or none" [1], "slightly below average" [2], "average" [3], "slightly above average" [4], and "a great deal" [5]. Vection magnitude ratings were obtained only during the second set of trials, and were based on the range of vection experienced across all linear, pitch, and roll trials during the first replication.

Results

An illustration of the center-of-pressure variations of a representative subject (BES) during clockwise and counterclockwise trials is shown in Figure 2, while changes in this same subject's y-axis moment over time are shown in the left-hand portion of Figure 3. The first significant postural response in the vast majority of subject trials was in the direction of scene motion. This tendency presumably occurred because the roll stimulus was similar to the visual motion normally experienced during a fall in the opposite direction, which elicits lateral vestibulospinal postural reflexes righting the body in the direction of scene motion (8). In addition to sustained lateral drifts in the center of pressure, visual roll motion led to a marked increase in sway amplitude (postural oscillations), presumably created by the conflict between visual and nonvisual postural control mechanisms. While all subjects exhibited both the postural biases and oscillations, the relative salience of these two components varied widely among them. Also, most subjects tended to show reduced postural drift and instability toward the end of the trial.

The latencies of the two different components of the postural response were quantified as shown in Figure 3. The *bias* component was extracted by smoothing the raw y-axis moment record using a 3-s averaging window (Figure 3a). The smoothed bias function was

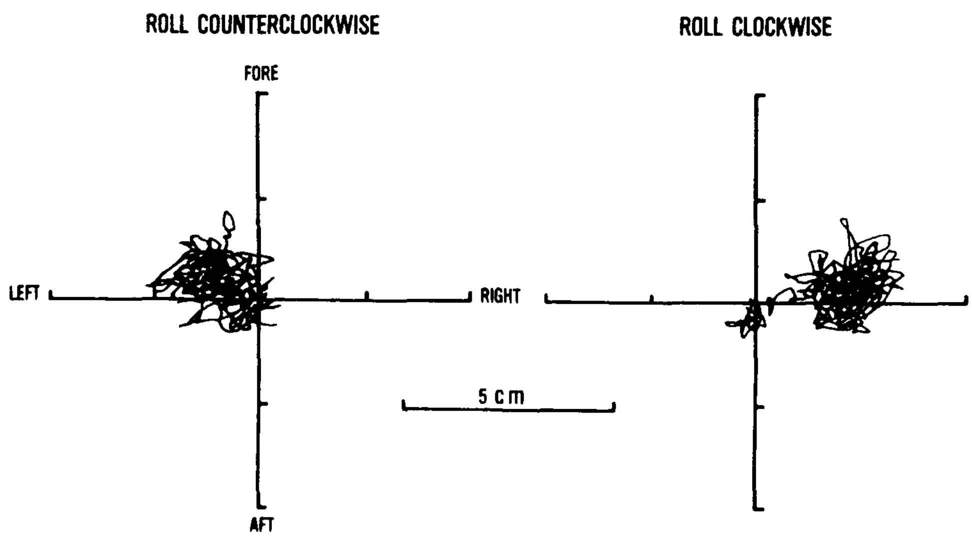

Figure 2. Stabilograms from subject BES showing the effects of clockwise and counterclockwise roll stimulation on postural sway. The continuous center of pressure during the stimulus interval is shown, referenced to the average center of pressure during the baseline interval (represented by the intersection of the ordinate and abscissa). Note the opposite postural biases obtained in the two roll conditions.

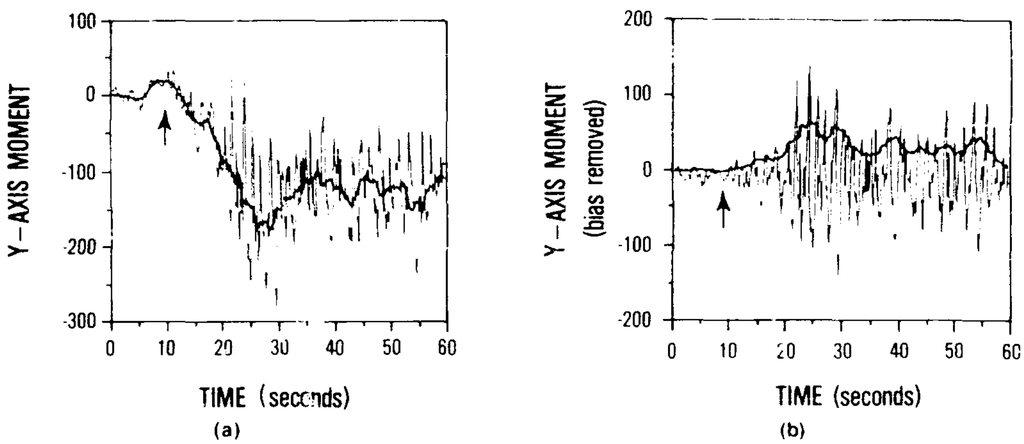

Figure 3. Changes in the *bias* and *oscillatory* components of the postural response over time, for the same data as shown in Figure 2. The bias component, shown as the darkened line in (a), was based on a sliding 3-s average of the raw moment data on which it is superimposed. The oscillatory component, shown as the darkened line in (b), was based on a removal of the smoothed bias component from the raw data and a calculation of the resultant rms amplitude using a sliding 3-s window. The arrow denotes the beginning of the stimulus interval.

then subtracted from the original record in order to isolate the postural oscillations that occurred during each trial. This record was used in turn to calculate a graph of root-mean-square (rms) amplitude over time, termed the *oscillatory* component (Figure 3b). The latency of each component was defined as the point at which its value first exceeded that of the baseline average by 3 standard deviations.[2]

The mean onset latencies of the postural bias and oscillatory components were 4.77 and 4.61 s, respectively, as compared to a mean vection latency of 7.13 s. A repeated-measures analysis-of-variance revealed this difference to be significant ($F(2, 22) = 9.2$, $P < .01$). Although the postural latency estimates were several seconds shorter than the vection estimate, they were nonetheless much longer than the postural delay found by previous researchers (7). Hence, it is conceivable that the poor signal-to-noise ratio on each trial led to an excessively high estimate of baseline variability and, in turn, a more conservative (that is, delayed) estimate of postural change onset. Consequently, the bias and oscillatory components were normalized and averaged across all 4 roll trials and all 12 subjects. Normalization was achieved by setting the initial and peak moment values during each subject trial to 0% and 100%, respectively. Using the averaged functions resulting from this procedure (Figure 4), the mean of the bias and oscillatory latencies was calculated to be 1.03 s.

A complete correlational matrix that included all 3 latency measures as well as all 3 magnitude measures (sway bias, sway amplitude, and vection magnitude) is shown in Table 1. Although the postural latencies correlated significantly with each other and with vection latency, their correlations with the magnitude measures were, with one exception, rather poor.

[2]A further restriction on the bias latency estimates was that they had to exceed the 3-standard-deviation criterion in the *same* direction as the stimulus motion. This restriction precluded a spurious postural change in the direction opposite to the major deviation from being recorded.

Discussion

The principal finding of this study is that visual roll motion—at least under the conditions of this experiment—induces postural

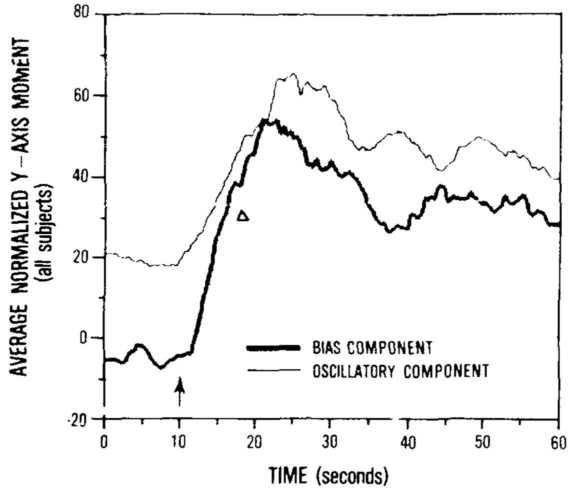

Figure 4. The averaged normalized bias and oscillatory components across all 12 subjects and all four roll trials. For each subject's data during a particular trial, the initial sample of the baseline interval was set to 0% and the peak amplitude throughout the trial set to 100%. The reason for the offset of the oscillatory function is that there was a limited amount of postural sway (that is, rms amplitude) even during the baseline interval. The arrow denotes the beginning of the stimulus interval, while "Δ" marks the mean vection latency averaged across all subjects.

changes that are manifested long before the onset of self-motion perception. Despite its delay, vection onset nonetheless appears to be highly correlated with the latency of postural change. Neither latency is predicted very well by the magnitude of postural change or vection that occurs, however.

The average vection latency obtained in this experiment lies in the outer range of those found by previous roll vection studies under similar visual conditions. For example, Watt and Landolt (5) obtained a vection onset latency of about 7 s using a 30°/s roll stimulus, although some studies have yielded slightly shorter estimates. One explanation for the marginally longer vection latency in this study is that the visual display subtended less than 100° in diameter, thereby eliminating a substantial portion of the peripheral visual field that is normally involved in maintaining spatial orientation. On the other hand, the considerably shorter postural latencies (1 to 2 s) obtained under identical conditions are highly consistent with the postural lag reported by Van Asten et al (7) using a visual display of a similar size. It is not clear why the postural latencies of Mauritz et al (9)—as illustrated in Dichgans and Brandt's Figure 11B—were several seconds longer, nor why the postural and perceptual effects in their study had such highly similar lags. Clearly, however, a delay of several seconds in the postural response to visual field shifts would render it functionally ineffective in helping prevent most naturally occurring falls.

Several explanations may be put forth as to why both this study and a previous one (3) found vection onset to be delayed relative to

Table 1. Latency and Magnitude Correlations (Pearson *r*-values)

	Sway (amp)	Sway (bias)	Vect (mag)	Vect (lat)	Bias (lat)	Osci (lat)
Sway (amp)	–	.05	−.33	−.22	−.22	−.59*
Sway (bias)		–	−.39	−.10	.26	.00
Vect (mag)			–	−.10	−.21	−.04
Vect (lat)				–	.66*	.73**
Bias (lat)					–	.66*
Osci (lat)						–

*$P < 0.05$. **$P < 0.01$

postural change. First, vection could be initiated as a direct consequence of the postural change, given that they correlate so highly with one another. But this is unlikely because a strong sensation of roll vection can occur in situations (for example, a seated or supine lie) wherein the magnitude of the postural tilt is presumably reduced or absent (4,5). Second, vection could be more delayed because it involves cortically mediated perceptual inferences to a greater extent (10,11,12,13), but recent evidence suggests that even visually mediated postural sway is influenced by "perceptual" factors such as foreground–background reversals (2). Third, vection could be more greatly inhibited by nonvisual (that is, vestibular and/or somatosensory/proprioceptive) signals during the initial period following the commencement of stimulus motion (1,6). Thus, the full strength of the visual scene would be experienced only after several seconds have elapsed and these other inputs have ordinarily decayed somewhat due to adaptation or, in the case of the vertical canals, decreased endolymph lag. This explanation is supported by the decreased vection latencies observed in at least one study under weightlessness (6), in which the output of the otoliths may be somewhat discounted because it no longer signals sustained shifts in body orientation.

Finally, it is possible that postural change and vection are manifestations of the same fundamental process, but that the latter merely has a higher threshold (and therefore longer onset delay). However, it is not clear if the "summated" strength of the visual signal is the critical determinant of either response latency. In confirmation of Watt and Landolt's findings, for example, neither latency measure correlated well with the magnitude measures, thereby suggesting that postural change and vection onset are not based on a simple integration of the visual signal over time. It is not altogether surprising that vection latency correlates only weakly with vection magnitude and postural sway amplitude, since self-motion perception is clearly dependent on higher order (nonlinear) perceptual processing. On the other hand, the rather elementary visual stimulus that was used in the present study makes it difficult to ascribe the considerable lag in vection onset entirely to visual perceptual factors.

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